Giant Planet Formation, Saturn and Uranus Entry Probes, and the Decadal

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This talk will focus on the past, present and the future of the origin and evolution of the giant planets and their atmospheres problem. The core accretion model has been the conventional model of the formation of the giant planets for four decades [1]. According to this model, a core formed first from grains of ice, rock, metals and refractory material of the protoplanetary nebula. Gases were trapped in these solids. Upon reaching a critical mass of 10-15 Earth Mass, the core gravitationally captured the most volatile of the gases, neon, hydrogen and helium from the surrounding nebula. This led to the gravitational collapse of the protoplanetary nebula. These last volatiles and the gases released from the core during accretional heating were the origin of the atmosphere. Thus the elemental abundance in the atmosphere would reflect that in the protoplanetary nebula, i.e. solar composition with the same abundance ratio to hydrogen as in the sun.

Surprisingly, the Galileo probe found the abundance of heavy elements (relative to H) in Jupiter's atmosphere enriched compared to the sun [2-4]. Moreover, the enrichment factor is uneven, varying from 2 to 6, i.e. the inter-elemental abundances are non-solar [5,6]! One missing piece of Jupiter's formation puzzle is the oxygen elemental abundance (O/H), however. Oxygen is sequestered in water in Jupiter, and the Galileo probe entered a 5-micron hotspot, the "Sahara Desert" of Jupiter, which was dry. The determination of water is critical to the models of the origin and evolution of Jupiter as water was presumably the original carrier of the heavy elements that formed the core. If enriched by a similar factor as the other heavy elements, water could comprise one-half of the mass of Jupiter's primordial core, or greater. Juno will measure and map water in Jupiter's troposphere by passive microwave remote sensing in 2016.

A comparison of the elemental abundances in Saturn with those in Jupiter is essential for constraining the formation models of the gas giant planets. However, remote sensing observations of Saturn from the Cassini orbiter have determined only one element, carbon, since remote sensing is not suited to measure the other heavy elements. A probe is required [6-8].

Finally, the models of the formation of the giant planets would be incomplete without similar heavy element data of the icy giant planets, Uranus and Neptune [9]. Only carbon is constrained in these planets, and the data have high uncertainty. The ice/gas ratio in these planets is 90-95% compared to 3-10% for the gas giants. Whether or not the icy giant planets followed a similar path of accretion as the gas giant planets can be understood only after the determination of a full suite of their elemental composition [5,9].

The NRC Planetary Decadal Survey (2013-2023) opens a path forward for entry probes into Saturn and Uranus. I will discuss also how within the available resources, both missions will be able to determine the elemental composition that is key to the models of formation of the giant planets in particular, the solar system in general, and, by implication, the extrasolar planetary systems.

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Author's own publications can be downloaded from www.umich.edu/~atreya.

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